Executive Summary

The National Parks and Monuments of the Colorado Plateau receive millions of visitors each year, attracted by outstanding scenic vistas and ecosystems that approach pristine conditions for the American West. Air quality is fundamentally important; imposing scenery needs to be visible to be appreciated. The potential impacts of changing air quality on ecosystems may be more subtle, including changes in the physiology of sensitive species which could lead to changes in community composition.

This project was initiated by the Air Resources Division of the National Park Service, with the objectives of summarizing:

1) Air quality and atmospheric deposition;
2) Sensitivity of terrestrial and aquatic ecosystems;
3) Current status of air quality related values (AQRVs);
4) Likely future status of AQRVs based on potential future air quality and ecosystem sensitivity;
5) Key areas requiring further research to clarify current impacts or likely future impacts.

The NPS has responsibility for 9 Class I areas in the Colorado Plateau: Arches National Park (ARCH), Black Canyon of the Gunnison National Monument (BLCA), Bryce Canyon National Park (BRCA), Canyonlands National Park (CANY), Capitol Reef National Park (CARE), Grand Canyon National Park (GRCA), Mesa Verde National Park (MEVE), Petrified Forest National Park (PEFO) and Zion National Park (ZION). This report also covers two nearby areas that are not generally considered as part of the Colorado Plateau: Bandelier National Monument (BAND) and Great Sand Dunes National Monument (GRSA).

The only documented impacts of air pollution on AQRVs in the Colorado Plateau involve visibility reductions. Air quality in this region is generally the best in the contiguous U.S., but visibility is moderately reduced for a substantial portion of the year for all Class I areas. Most of the atmospheric light extinction on the Colorado Plateau results from roughly equal contributions of sulfate, organics, and soot aerosols. Reductions in visibility from sulfate may be marginally alleviated in the future, depending on the degree to which emissions of SO_2 are reduced from existing sources or increased by additions of new point sources. Given that low-visibility days are due in large part to high concentrations of sulfate aerosols, any increase or decrease in S emissions should directly affect visibility.

No effects of ozone have been reported on the Colorado Plateau. Very little work has focused on the sensitivity of plants in this region to ozone. In general, the peak concentrations of ozone are low relative to the concentrations expected to produce visible injury to plants from other regions. Some recorded peaks have been high enough that some injury might be expected, but 1) no injury has been reported, and 2) high water stress may reduce plant exposure to ozone by reducing stomatal conductance. The levels of cumulative ozone exposure (calculated as the sum of the parts-per-billion in excess of 60 for 12 hr/day for 90 days) in some cases fall within the range where chronic effects (such as growth reductions) may be expected. However, no systematic surveys have examined the Class I areas of the Colorado Plateau for foliar injury or growth reductions. We expect that any current impact of ozone exposure on plants probably ranges from negligible to minor, but a systematic survey is recommended (see below). Ambient concentrations of SO_2 are far below thresholds for impacts on sensitive plants.

In general, surface waters and watersheds of the Colorado Plateau are resistant to chemical change due to low levels of acidic deposition and to the nature of the region's hydrogeology. Some of the park units discussed in this review have some portions that are characterized by bedrock resistant to weathering (e.g. Great Sand Dunes National Monument). Small pools, ponds, and streams found on more crystalline rock may be susceptible to change due to atmospheric inputs. A potentially important data gap is the potential for aquatic system change due to nitrogen inputs to both the aquatic and terrestrial ecosystems of the Colorado Plateau. Current rates of deposition probably exceed pre-industrial conditions, but no impacts on AQRVs are apparent. The NADP monitoring data show significant declines in S deposition at some sites on the Plateau, and no trends in N deposition.

Recommendations

Our synthesis showed that visibility differs among the Parks and Monuments of the Plateau. Therefore, air quality at one location cannot in general be extrapolated simply from other sites because of differences in major sources of pollution, distances from sources, and weather patterns. Regional visibility conditions are currently assessed using the IMPROVE Protocol at several sites on the Colorado Plateau; other Class I areas of the Plateau have limited or no visibility monitoring. We recommend:

- Additional monitoring for specific units and resources for special studies, including more work to identify the contribution of specific point sources and of urban centers (particularly Las Vegas and urban centers in California) to visibility impairment.

No impacts on AQRVs have been reported for ozone; the lack of injury reports could indicate no effects have occurred, or a lack of a thorough reconnaissance by experts who can identify foliar injury. We recommend:

- A reconnaissance survey of all Class I NPS areas to determine if foliar injury from ozone is occurring. A single late-summer expedition would show the extent of any current problem and whether follow up surveys (in more depth) are warranted. This reconnaissance-level survey could be repeated after any summer with notably high ozone concentrations.

The monitoring of effects of deposition (both wet and dry) on surface waters needs to be continued or expanded. No estimates of rates of dry deposition are currently available for the Colorado Plateau. We recommend:

- An attempt be made to estimate dry deposition rates. This work would need to examine and improve the algorithms that are currently used to translate ambient concentrations of dry species to deposition loadings.

Too little is known about the biogeochemistry of small ponds and rock pools to know if increasing deposition of N (or S) could alter these unique ecosystems. We expect no major impacts at present, but we recommend:

- pH, ANC, sulfate-S, ammonium-N, and nitrate-N, and biological properties should be monitored for water bodies with ANC < 200 μeq/L and those on resistant bedrock (such as quartzite). Park staff review the surface water chemistry data with USGS researchers periodically to identify waters that might be sensitive to changes due to deposition.

The National Park Service has a policy and obligation to develop baseline inventories of the natural resources protected within the National Parks and Monuments. Most parks have incomplete species lists, only partial geographic information on location of species and communities, and few have any monitoring program that would identify moderate changes in ecosystem health. Substantial changes in vegetation are likely to develop in the coming decades, as a result of natural succession processes, fire regimes (including suppression, prescribed fire, and wildfire), responses to grazing (or cessation of grazing), visitor impacts, impacts of changing wildlife populations, and from driving forces such as pollution and climate change. The role of pollution in these changes can only be determined by adequate characterization of the nature and extent of changes, coupled with experimental information to determine the likely causes of the changes. We recommend:

- That broad-based resource monitoring in the Parks and Monuments be given a high priority.

Monitoring activities need to be supplemented by process-level experimentation to identify the likely AQRV impacts of air pollutants. We recommend:

- An experimental focus on the episodic change in chemistry of sensitive water during large events. Sensitive systems are most likely to show changes in chemistry and biota following large rain storms that flush accumulated dry deposition in small pools and streams. Where appropriate, rainfall events could be monitored, and short term responses in stream or pool chemistry could be studied (using automatic sampling devices). Before reaching conclusions about the effect of chemical changes on biota, controlled dose/response experiments would be needed (using native vertebrate and invertebrate species).
- A wide range of plant species needs to be screened in controlled fumigation experiments for sensitivity to ozone (in the range of 40 to 60 ppb average, with peak exposures of 100-120 ppb). These fumigations need to include manipulations of water supply (for at least a subset of the species) to examine the effects of moisture stress on reducing the ozone impacts on the plants. Another possible approach for examining potential impacts of current ozone levels would be testing plants on-site in charcoal-filtered air; open top chambers could be placed around established plants with and without filtered air treatments. Any increased growth in the filtered chambers would be consistent with an ozone-induced effect on growth.
- The pollutant of most concern relative to setting of critical loads is N because of the likely increase in the emissions of nitrogen oxides and ammonia due to human activities. Experimental additions of N (on the order of 10 to 20 kg N ha^{-1} yr^{-1}) are needed to a

wide variety of ecosystems (from grasslands, shrublands and forests to potholes and streams) to provide a basis for insights about critical loads of N deposition in the Colorado Plateau.

We conclude that air quality in the Colorado Plateau is generally good; the major AQRV known to be impacted currently is visibility. No major or rapid changes are expected in the next decade or two; gradual changes in emissions may produce discernible changes in visibility. Research is needed to determine if AQRV of vegetation and surface waters are being affected at current levels of pollution.

Acronyms, Abbreviations, and Units

A.D.	*Anno Domini*
ADP	Adenosine Diphosphate
AIRS	Aerometric Information Retrieval System
ANC	Acid Neutralizing Capacity
AQRV	Air Quality Related Value
ARCH	Arches National Park
ARD	Air Resources Division (of the National Park Service)
ATP	Adenosine Triphosphate
b_{ext}	Atmospheric Extinction Coefficient
BAND	Bandelier National Monument
BLCA	Black Canyon of the Gunnison National Monument
BLM	Bureau of Land Management
BRCA	Bryce Canyon National Park
CANY	Canyonlands National Park
CARE	Capitol Reef National Park
CO	Carbon Monoxide
$^{14}CO_2$	Carbon Dioxide (^{14}C isotope)
EPA	U.S. Environmental Protection Agency
GCVTC	Grand Canyon Visibility Transport Commission
GIS	Geographic Information System
GRCA	Grand Canyon National Park
GRSA	Great Sand Dunes National Monument
H^+	Hydrogen Ion
HNO_3	Nitric Acid
H_2SO_4	Sulfuric acid
HSO_3^-	Bisulfite
IMPROVE	Interagency Monitoring of Protected Visual Environments

IPCC	Intergovernmental Panel on Climate Change
MEVE	Mesa Verde National Park
MOHAVE	Project MOHAVE, EPA study of air flow and pollution transport
N	Nitrogen
NAAQS	National Ambient Air Quality Standards
NADP	National Atmospheric Deposition Program
NAPAP	National Acid Precipitation Assessment Program
NAWQA	National Ambient Water Quality Assessment
N_2	Dinitrogen
N_2O	Nitrous Oxide
NH_3	Ammonia
NH_4^+	Ammonium
NM	National Monument
NO_2	Nitrogen Dioxide
NO_2^-	Nitrite
NO	Nitric Oxide
NO_x	Nitrogen Oxides
NO_3^-	Nitrate
NP	National Park
NPS	National Park Service
O	Oxygen Atom
O_2	Molecular Oxygen
O_3	Ozone
OH-	Hydroxyl
PAN	Peroxylacyl Nitrate
PEFO	Petrified Forest National Park
PM	Particulate Matter
PM_{10}	Particulate Matter (diameter less than 10 microns)
PSD	Prevention of Significant Deterioration
S	Sulfur
SCENES	EPA Study on Visibility
SO_2	Sulfur Dioxide
SO_3^{2-}	Sulphite
SO_4^{2-}	Sulfate
SO_x	Sulfur Oxides
SVR	Standard Visual Range
U.S.	United States
USDA	U.S. Department of Agriculture
USFS	U.S. Forest Service
USGS	U.S. Geological Survey
USFWS	U.S. Fish and Wildlife Service

VOC	Volatile Organic Compounds
WHITEX	Winter Haze Intensive Tracer Experiment
ZION	Zion National Park

Units

^{o}C	degrees Celsius
cm	centimeter
dv	deciviews
g	gram
ha	hectare
hr	hour
kg	kilogram
km	kilometer
L	liter
m	meter
mg	milligram
mm	millimeters
Mm	megameters
MW	megawatt
μeq	microequivalent
μg	microgram
μm	micrometers
μS	microsiemens
ppb	parts per billion
yr	year